OBSERVATIONS AND SIMULATIONS OF RECURRENT NOVAE: U SCO AND V394 CRA

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ABSTRACT

We present observations and analysis of the August 1987 outburst of the recurrent nova V394 CrA. This nova was extremely fast and its outburst characteristics closely resembled those of the Recurrent Nova U Sco. In addition to the observations, we have performed hydrodynamic simulations of the outbursts of recurrent novae and present a summary of these results as applied to the outbursts of V394 CrA and U Sco.

1. INTRODUCTION

The IUE Satellite has observed four recurrent novae during its 10 year lifetime. These are WZ Sge, U Sco, RS Oph and V394 CrA. The ultraviolet data showed that WZ Sge was a long period dwarf nova and, therefore, its outburst is not relevant to this work which is concerned only with recurrent classical novae. The 1979 outburst of U Sco was well studied both in the ultraviolet, with the IUE Satellite, and in the optical (Williams et al. 1981). The May 1987 outburst was well studied in the optical (Sekiguchi et al. 1987) but the nova was too close to the sun to be studied with the IUE Satellite. Recently, some of us have published simulations of its 1979 outburst (Starrfield, Sparks, and Truran 1985).

RS Oph is more of a puzzle and its outburst resembles that of a nova exploding into a stellar wind. In addition, there is some controversy about what caused its outburst. A summary of its behavior can be found in the proceedings of a symposium held specifically to discuss its outburst and that of other recurrent novae (Bode 1986).

V 394 CrA exploded in August 1987 and we were able to obtain both optical and ultraviolet data. A previously recorded outburst occurred in 1949 (Duerbeck 1987). These data are now being analyzed and this nova appears to have had an outburst similar to that of U Sco. The data from this outburst will be presented and discussed in this paper. In a companion study, we have done new simulations for the outbursts of both U Sco and V 394 CrA. We assumed a $1.35 M_\odot$, hot white dwarf accreting at high rates. Given mass accretion rates as high as $10^{-6} M_\odot yr^{-1}$, it is possible to achieve a runaway in less than 3 years from the beginning of accretion. These calculations have been done with new boundary conditions that include the effects of the accretion energy on the thermonuclear runaway. They also include the effects of radiation pressure driven mass loss.

2. The 1987 Outburst of V394 CrA

V394 Coronae Austrinae was reported to be in outburst by Liller (IAU Circular 4428) who also noted that spectra taken on August 3.021, 1987 showed intense Hα emission blended with [NII] plus a weak continuum. McNaught (IAU Circular 4429) noted the coincidence in position of V394 CrA with a star of mag ~18 on a UK Schmidt J Plate at a position of $\alpha = 17^h 56^m 58.18^s$, $\delta = -39^\circ 00'29.3''$. Some of us began obtaining spectra with the CTIO 1-meter telescope on August 4, 1987 and reported that the nova (IAU Circular 4430) showed broad emission from the Balmer lines, He I, and He II 4686Å. In addition these spectra also showed strong recombination lines from NII at 5005Å, 5679Å, and 5178Å). A spectrum obtained on August 4, 1987 is shown in Figure 1a and a spectrum obtained on August 19, 1987 is given in Figure 1b. Note the rapid evolution and decay of the emission lines over the two week interval. Exactly the same behavior was found for U Sco (Barlow et al. 1981). Note also that at all times HeII 4686Å is stronger than Hβ. This inversion of line strengths is unusual but also seen in U Sco and some of the other old novae. However, we also note that V1500 Cygni 1975, which also shows HeII 4686Å stronger than H beta has been found to be an AM Her variable (Schmidt, Stockman, and Lamb 1988, preprint).

Unfortunately, we were unable to obtain an IUE spectrum

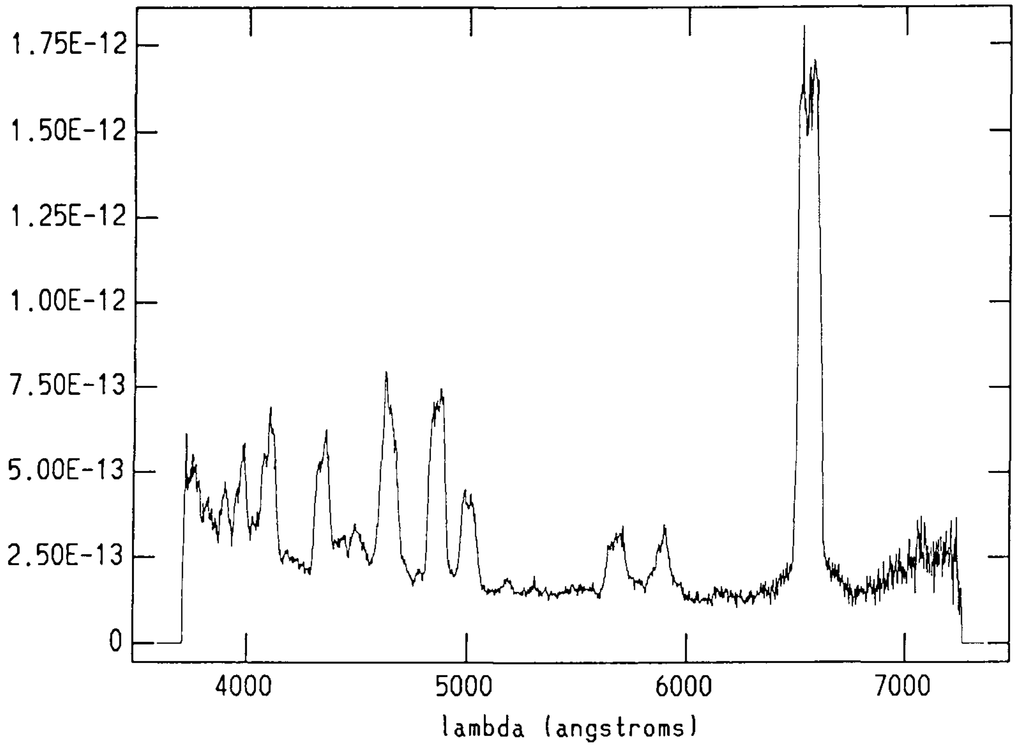

Figure 1a. The optical spectrum of V394 CrA obtained on August 4, 1987. The line identifications for the strongest lines can be found in Table 1. Note the strength of HeII 4686Å as compared to Hβ. The structure in Hα is certainly real and characteristic of novae ejecta.

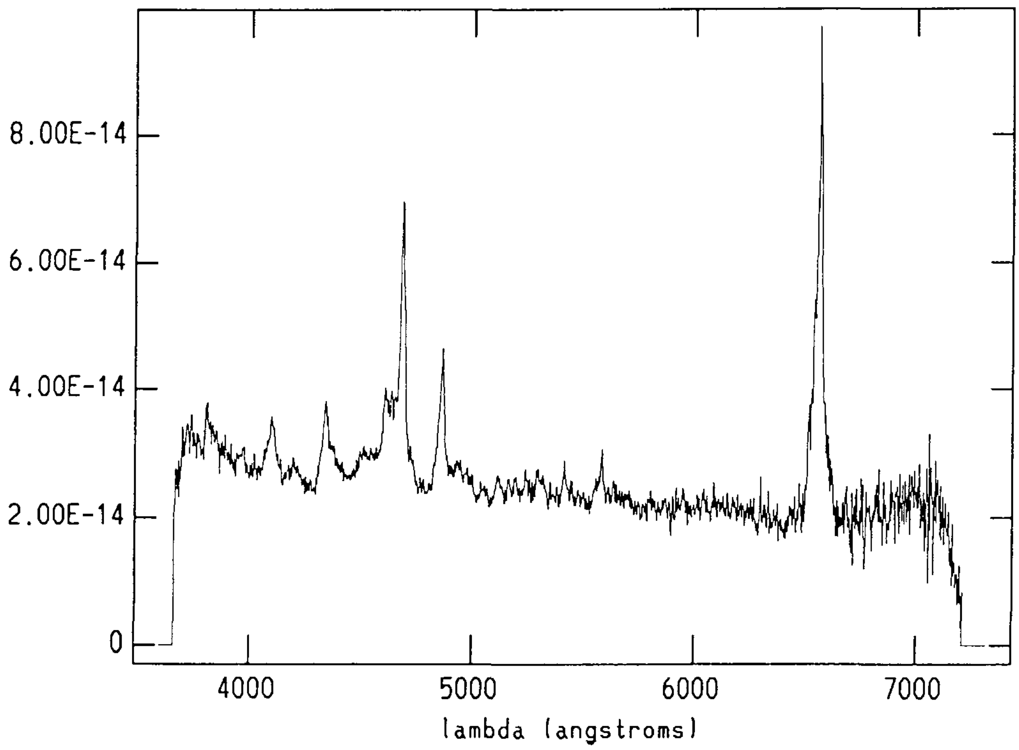

Figure 1b. The optical spectrum on August 19, 1987. The nova declined very rapidly over the two week period. This behavior is analogous to that of U Sco. However, the 4640Å complex was much stronger in U Sco than in this nova.

until August 23, 1987 and by then the nova had faded considerably. We show this spectrum as Figure 2a and 2b. We give the entire usable spectrum in Figure 2a in order to demonstrate the excellent match to a spectrum that we obtained of the Recurrent Nova U Sco on June 30, 1979 (Williams et al. 1981). In Figure 2b. we show only the region from 1300Å to 1950Å in order to show the profiles of CIV 1550Å and NIII] 1750Å in more detail. Note that the same blend at 1750Å appears in the June 30, 1979 spectrum of U Sco. We do not have an identification for the line at ~1735Å. The most important features to notice about this spectrum is the great strength of the nitrogen lines. Their strength strongly supports the suggestion of Heathcote, Gomez, and Williams (IAU Announcement Card #4430) that nitrogen is enhanced in this nova.

3. Discussion

The strong resemblance of both the optical and ultraviolet spectra of V394 CrA to those obtained of U Sco during its 1979 and 1987 outbursts (Barlow et al. 1981; Williams et al. 1981; Sekiguchi et al. 1987) strongly suggests that these objects are closely related. A high priority of future optical observations should be a study of both recurrent novae at minimum in order to determine the parameters of the binary systems.

The current hydrodynamic modeling of recurrent novae (see Starrfield, Sparks, and Shaviv 1988, and references therein) implies that we are witnessing the effects of thermonuclear runaways on very massive white dwarfs. This conjecture can be tested by radial velocity studies of these two systems at minimum. In fact, their outbursts are so rapid that they have already returned to minimum but are not too faint to be studied with large telescopes in the southern hemisphere.

The theoretical studies of these systems also show that it is possible to obtain a thermonuclear runaway and mass ejection even if the secondary is transferring material with no CNO enhancement. The luminosity of the shell source is sufficient to drive mass from off of the white dwarf purely by radiation pressure. However, only a small fraction of the accreted mass is ejected during the outburst; most of it is burnt to helium during the runaway and acts purely to increase the mass of the white dwarf towards the Chandrasekhar limit. Therefore, we predict that these two systems, U Sco and V 394 CrA, are evolving to a point where the white dwarf will exceed a mass of $1.4M_\odot$ and become a neutron star. These systems will then become low mass X-ray binaries. An argument in favor of this suggestion is that the low mass X-ray binaries seem to be transferring material rich in helium (Williams 1988, in preparation).

Acknowledgements

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TABLE 1

Identification	Wavelength (Å)
Lyα	1216Å
NV	1240Å
NIV]	1486Å
CIV	1549Å
HeII	1640Å
OIII]	1663Å
NIII]	1750Å
Hδ	4101Å
Hγ	4340Å
He II	4686Å
Hβ	4861Å
NII	5005Å
NII	5178Å
HeII	5411Å
NII	5679Å
HeI	5876Å
Hα	6563Å

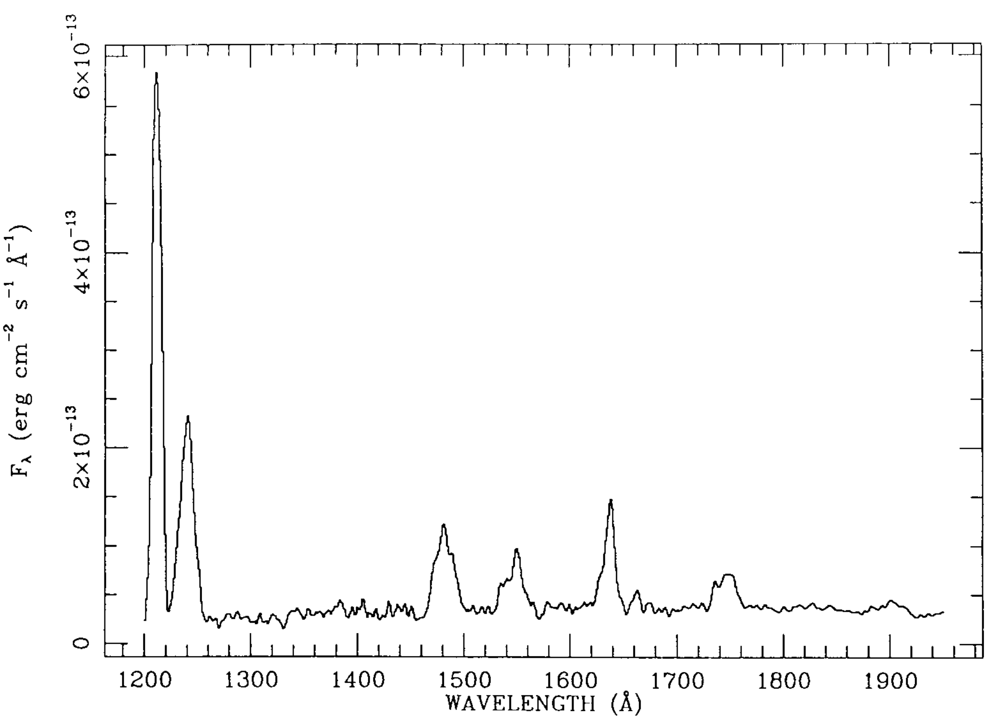

Figure 2a and b. The IUE spectrum of V394 CrA obtained on August 23, 1987. The upper plot shows the entire usable spectrum while the lower plot emphasizes the strong lines and shows the peculiar profile around NIII] 1750Å. This spectrum closely resembles that of U Sco obtained on June 30, 1979.